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North-South asymmetry of the solar parameters during the different solar cycles

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Abstract

Data of the solar and interplanetary parameters (IMF magnitude *B*, Solar wind speed *V*, Proton density *n*, and the Proton temperature *T*) during the period from 1975 to 2013, have been used to examine the asymmetry between the solar field north and south of the eliospheric current sheet (HCS). In this work, the asymmetry of the IMF magnitude is obvious, and has no magnetic solar cycle dependence over the considered epochs. The solar wind speed *V* is faster by about 26.9 km/s for toward polarity days than for away polarity days when the IMF points away from the Sun north of the current sheet and toward the Sun south of it. In addition, the solar plasma was more dense, hotter, and faster north of the HCS than south of it during cycles 22, and 23. Large asymmetries in *V*, *n*, and *T* occurred in 1994. Finally, we conclude that the asymmetry is real, and is a good indicator in studying the solar activity.

Keywords: Interplanetary parameters; North-South asymmetry of IMF; Solar activity distributions

1. Introduction

Our Sun influences and shapes the region of interplanetary medium, otherwise known as the heliosphere; the physical conditions within this space are under the influence of the Sun. Most interplanetary plasma parameters are highly variable on time scales ranging from minutes to solar activity cycle and also vary with heliospheric latitude and longitude [1]. The solar magnetic field is frozen in the solar plasma and carried outward by the solar wind. According to the rotation of the Sun, the magnetic field at equatorial latitudes forms a spiral structure. Adding to this, the neutral sheets result from this structure, maintaining a separation between northern and southern regions. This averaged warped heliospheric current sheet (HCS) separates regions with opposite polarities of the magnetic field. The structure of the HCS changes substantially during the 11-year sunspot Cycle [2–5], with a relatively flat sheet at the solar minima years, but neutral sheet waves extend up to 70° heliolatitude at solar maxima epochs. In addition, the solar field polarity reverses at each solar maximum

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giving rise to a 22-year periodicity in the heliomagnetic field. The asymmetry of the interplanetary plasma, solar indices, and the cosmic ray between the northern and southern heliospheric current sheet has been the subject of many studies and has been discussed by several authors [6–15].

The work [16] showed that the N-S asymmetries are found in the declining and increasing phases, as well as times of maxima for all solar cycles that he studied.

Sanalkumaran and Prabhakaran [17], examined the N-S asymmetry for IMF, Ap, and V during the four cycles (20–23) and he found the phase of the asymmetry of IMF reverse every cycle, and the asymmetry of the Ap index appears similar to that of solar wind velocity and may be due to the existence of relic magnetic field in the solar convection zone. The Sun's magnetic activity is generally believed to be supplied by a hydromagnetic dynamo operating either in or at the base of the solar convective zone. Dynamo models predict the possibility of mixed parity solutions where the field has both dipolar and quadrupolar components. Such fields would be asymmetric with respect to the equator. Indeed, there is evidence that the Sun's field was highly asymmetric as it emerged from the Maunder Minimum [18]. Javaraiah and Ulrish [19] indicated that, there are considerable North-South differences in the differential rotation rates and the meridional motions of sunspots. Helioseismology measurements also show the existence of N-S differences in the solar rotation and meridional flow [20].

Beside that El-Borie et al. [21], examined the N-S asymmetry for the plasma parameters and the solar indices an he said that the N-S asymmetry for the solar plasma was more dense north of the current sheet than south of it during the second negative solar polarity epoch ($qA < 0$). In the present work, we examine the N-S asymmetries in the solar and interplanetary parameters (Field magnitude (B), Solar wind speed V, Proton density n, and the Proton temperature T) during the period from 1975 to 2013.

2. Data resources and method

In this work, used the daily data for the solar and interplanetary parameters (Field magnitude B (nT), solar wind speed V (Km/s), Proton density n (n/cm^3), and the proton temperature T (Kelvin)). These parameters have been analyzed according to the IMF sector to examine the presence of the North-South asymmetry during the period 1975–2013. Most of the daily data are available at the National Space Science Data Center (NSSDC) as an OMNI data base. The field direction is calculated on a daily basis in the geocentric solar ecliptic coordinate system. Then, we have separated the field direction into two polarities; away (A) polarity if the solar ecliptic azimuthally angle of the IMF daily averages lies between 45° and 225°; otherwise it is considered toward (T) the Sun. We have removed days on which the IMF is truly mixed and separated the considered data into two groups according to the away or toward daily average IMF vector, over the considered period.

The N-S asymmetry for the considered parameters has been calculated by using the following equation:

$$\text{Asymmetry} = T - A$$

T and A are the yearly average values of the parameter for toward and away days. It is important to note that during the negative solar polarity, toward sectors measurements correspond to northern hemispheric field and away sector measurements correspond to southern hemispheric fields. During the years of positive solar polarities the association is reversed.

3. Results and discussion

In this section, we have examined the asymmetry that exists between the very large-scale properties of toward and away sectors of solar parameters. The asymmetry between the northern and southern hemispheres sunspot activity is well known to solar observers and is one of the features used in the morphological description of the solar activity. The northern and southern active periods are generally quite different when long-term activity is considered. Throughout the period of solar cycles 12–21 (1878–1988), the N-S asymmetry of the sunspot numbers with respect to the solar equatorial plane has been studied [9].

Fig. 1 displays the yearly variations of the difference of the field magnitude B, between toward and Away

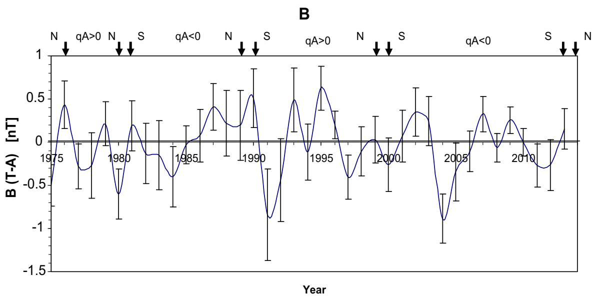

Fig. 1. The annual differences between the field magnitude north and south of the current sheet, during the period from 1975 to 2013. Times of Sun's north (N) and south (S) pole reversals of magnetic polarities are displayed by arrows in the top panel.

Table 1
The average values of the North-South asymmetry for the field magnitude and the solar parameters during the +ve & −ve IMF polarity cycle for cycle 21.

IMF & solar parameters	Positive polarity (1976–1978)			Negative polarity (1981–1986)		
	265 toward days Average	341 away days Average	$T-A$ Average	730 toward days average	711 away days average	$T-A$ Average
Solar cycle 21 (June 1976–Sep 1986)						
V	414.47 ± 5	432.56 ± 5	−18.1 ± 29.8	467.18 ± 4	456.80 ± 3.8	10.38 ± 18.8
n	8.58 ± 0.3	8.01 ± 03	0.57 ± 0.4	7.62 ± 0.2	7.82 ± 0.2	−0.20 ± 0.23
T (10^3 K)	104.2 ± 4.5	119.3 ± 5	−15.1 ± 29.7	136.8 ± 3.7	130.4 ± 3.4	6.4 ± 16.6
B (nT)	6.28 ± 0.4	6.31 ± 0.5	−0.03 ± 0.7	7.31 ± 0.5	7.48 ± 0.5	−0.16 ± 0.7

Table 2
The average values of the North-South asymmetry for the field magnitude and the solar parameters during the +ve & −ve IMF polarity cycle for cycle 22.

IMF & Solar parameters	Positive polarity (1991–1996)			Negative polarity (1986–1988)		
	652 toward days Average	630 away days Average	$T-A$ Average	256 toward days average	235 away days average	$T-A$ Average
Solar cycle 22 (Sep 1986–May 1996)						
V	472.76 ± 4.7	445.86 ± 4.3	26.90 ± 23.2	439.67 ± 6.1	433.45 ± 5.4	6.2 ± 0.435.3
n	7.72 ± 0.2	8.59 ± 0.23	−0.87 ± 0.26	8.28 ± 0.3	7.79 ± 0.28	0.49 ± 0.4
T (10^3 K)	167.3 ± 4.5	142.1 ± 6	25.2 ± 41.1	111 ± 4.8	112.2 ± 4.9	−1.2 ± 29.8
B (nT)	6.72 ± 0.5	6.92 ± 0.7	−0.20 ± 0.8	6.75 ± 0.5	6.64 ± 0.3	0.28 ± 0.5

days for both positive and negative polarity epochs. The error bar is considered for each year in each parameter. Times of the magnetic field reversal at the Sun's north (N) and south (S) poles are noted at the top of the figure. It is important to remember that during the negative solar magnetic polarity the toward sector occurs north of the current sheet and south of the current sheet during positive polarity. From this panel, eight clear positive asymmetry with toward values higher than the away values appeared in (1976, 1987, 1990, 1993, 1995, 2002, 2007, and 2009). The maximum positive asymmetry happened in the year 1995 with a magnitude (0.625 ± 0.3 nT).

In contrast, there are 7 negative asymmetries showed in (1975, 1980, 1984, 1991, 1997, 2004, and 2011) with largest negative asymmetry in the year 1991 (-0.837 ± 0.5 nT), and another one occurred during the second negative polarity (2001 to the present) in the year 2004 (-0.885 ± 0.3 nT). Tables 1–4 display the average values of the North-South asymmetry for the solar parameters during the +ve & −ve IMF polarity cycle thought the four solar cycles (21, 22, 23, and 24). From these tables, one can note that the grand average differences of the field magnitude north and south of the HCS are very low for positive (qA < 0) and negative (qA > 0) polarity epochs during the four solar cycles.

Table 3
The average values of the North-South asymmetry for the field magnitude and the solar parameters during the +ve & −ve IMF polarity cycle for cycle 23.

IMF & solar parameters	Positive polarity (1996–1998)			Negative polarity (2001–2008)		
	387 toward days Average	438 away days Average	$T-A$ Average	1127 toward days average	1192 away days average	$T-A$ Average
Solar cycle 23 (May 1996–Jan 2008)						
V	396.66 ± 3.3	407.48 ± 3.6	−10.8 ± 15.9	450.95 ± 3.1	473.06 ± 3.3	−22.11 ± 14
n	8.03 ± 0.2	7.75 ± 0.2	0.28 ± 0.24	6.05 ± 0.1	5.65 ± 0.1	0.40 ± 0.13
T (10^3 K)	112.2 ± 4	126.1 ± 4.2	−13.9 ± 21.4	110.6 ± 2.3	122.8 ± 2.6	−12.2 ± 9.01
B (nT)	5.88 ± 0.5	5.89 ± 0.5	−0.01 ± 0.6	6.27 ± 0.5	6.23 ± 0.5	0.04 ± 0.7

Table 4
The average values of the North-South asymmetry for the field magnitude and the solar parameters during the −ve IMF polarity cycle for cycle 24.

IMF & Solar parameters	Negative polarity (2008–2012)		
	908 toward days Average	657 away days Average	$T-A$ Average
Solar cycle 24 (Jan 2008–present)			
V	421.74 ± 3.2	407.29 ± 3.4	14.45 ± 14.9
n	5.09 ± 0.1	5.59 ± 0.1	−0.50 ± 0.12
T (10^3 K)	87.9 ± 2.1	78.1 ± 2.1	9.8 ± 6.6
B (nT)	4.71 ± 0.3	4.74 ± 0.4	−0.03 ± 0.5

This means that there is no remarkable N-S asymmetry in the averaged field magnitude over the former epochs and there is no magnetic solar cycle dependence is evident.

Fig. 2 displays the yearly difference averages in n, V, and T between toward and away polarity days for the 39 years interval 1975–2013. The notations are the same as in Fig. 1. Plot 2a, Shows the N-S asymmetry of the proton density n, when the error bar is taken into our account, we found 14 random years out of 39 years with North-South asymmetry. Nine of them have a clear positive asymmetry with average n of the northern heliospheric densities higher than the average of the southern heliospheric densities which occurred in (1977, 1979, 1986, 1988, 1999, 2001, 2003, 2007, and 2009) with maximum values in 1999 (1.4 ± 0.5), and 2007 (1.4 ± 0.4).

In contrast, five years have clear negative asymmetry (1981, 1994, 1997, 2010, and 2012) with the largest value obtained in year 2010 (-1.4 ± 0.4). In addition, Table 4 displays that the average proton density in a away polarity days south of the HCS during the 2008–2012 epoch is 0.5 ± 0.12 n/cc more dense than of toward polarity days north of the HCS. From the other side Table 2 shows that the average proton density in a away polarity days north of the HCS during the 1991–1996 epoch is 0.87 ± 0.26 n/cc more dense than of toward polarity days south of the HCS. So we can conclude that, the solar plasma is more dense south the current sheet than north

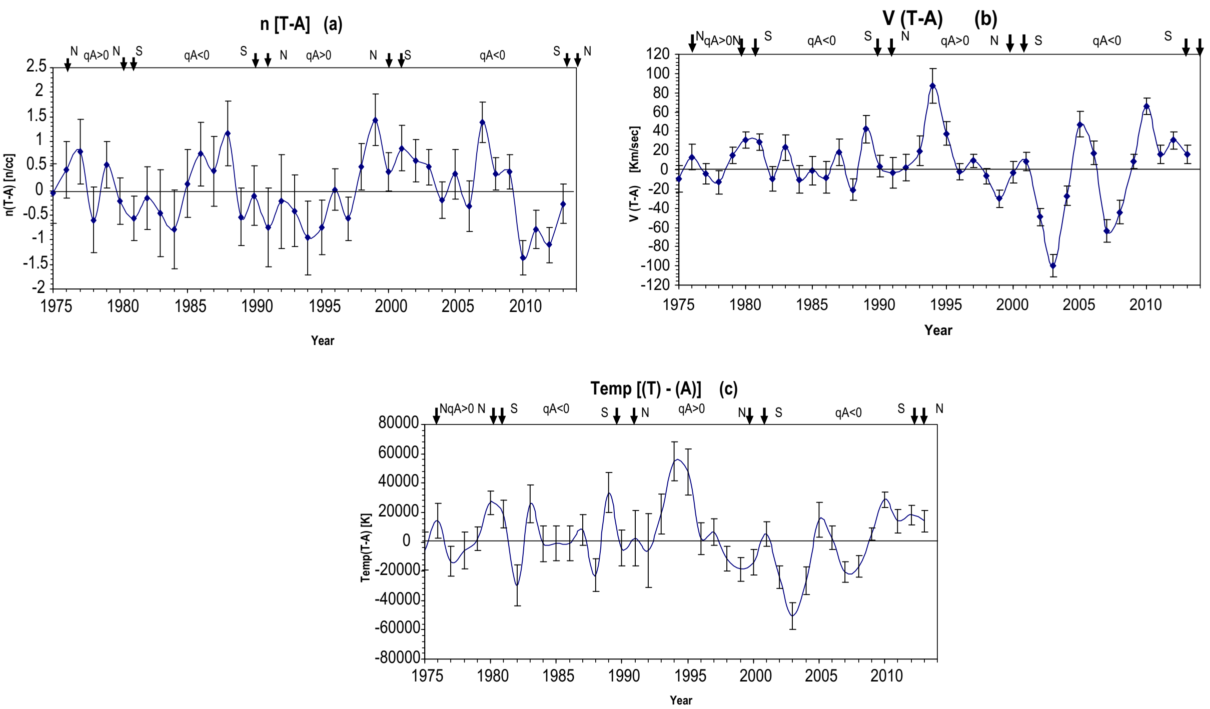

Fig. 2. The difference between the yearly averages of the magnitude for n (a), V (b), and T (c) between the north and south of the current sheet over the 39 year period from 1975 to 2013.

of it during the cycles 21 and 24 (see Tables 1 and 4). In contrast the solar plasma is more dense north than south of the current sheet during the cycles 22 and 23 (see Tables 2 and 3).

Plot (2b, and 2c), show that the asymmetry of the V is typically the same for Proton temperature with almost positive and negative asymmetry peaks with largest positive asymmetry obtained in 1994 (87.1 ± 17.1 km/s and $54.6 \pm 1.3 \times 10^3$ K) near to the minimum of the solar cycle, and largest negative asymmetry placed in 2003 (87.1 ± 17.1 km/s and-$50.7 \pm 8.9 \times 10^3$ K) in the descending phase of the cycle 23 for the V and proton temperature T, respectively.

From Table 2, one can note that the asymmetry for V, and T reached to its maximum for the epoch 1991–1996 ($qA < 0$) which mean that the plasma density south of the current sheet is hotter than north of it and V are faster by about 26.9 ± 23.2 km/s for toward polarity days than for away polarity days when the IMF points away from the Sun north of the current sheet and toward the Sun south of it. From the other three tables, one can note that the solar plasma south the current sheet is hotter and faster than north of it during the cycles 22 and 23. In contrast the solar plasma north is hotter and faster than south of the current sheet during the cycles 21 and 24.

4. Conclusion

The North-South asymmetry is an open question at this moment, and there are many theories trying to explain the reasons for this asymmetry. In this work, the daily solar parameters data (Solar wind speed V, field magnitude B, Proton density n, and the Proton temperature T) have been analyzed according to the IMF sense to examine the presence of the asymmetry between the northern and southern heliospheric current sheet over the period 1975–2013. From our work we got that:

1. The yearly North-South asymmetry of the field magnitude is clear over the considered period. From the other hand, there is no remarkable N-S asymmetry in the averaged field magnitude over the considered epochs, as well as there is no magnetic solar cycle dependence.
2. During cycles 21 and 24 the solar plasma north of the current sheet is less dense, hotter, and faster than south of it.
3. While during cycles 22, and 23 the solar plasma south of the current sheet is less dense, hotter, and faster than north of it.
4. Large asymmetries in V, n, and T placed in 1994.
5. Finally, the one conclude that the asymmetry is real, and is a good indicator in studying the solar activity. In addition, this asymmetry may produce another asymmetry in the solar diurnal variations of the galactic cosmic rays.

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